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TRANSISTORIZED OSCILLATOR TYPE CONTROLLER

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I. PREFACE

With recent expansion of the application range of automation has come a demand for a controller that indicates, warns and controls accurately and yet is simple to operate, inexpensive and completely reliable.

To meet this demand, Fuji Electric has manufactured the TZ type controller, incorporating many outstanding features. With this TZ controller as the basis, Fuji Electric has produced a transistorized controller, Model TZ-II (abbreviated name: TRANZET): performance characteristics have been much improved and its handling has been greatly simplified.

This transistorized oscillator type controller, TZ-II, utilizes a highly accurate, stabilized and unique span-band suspension moving-coil type galvanometer and a transistor circuit; it is stable against vibration and variations of environmental temperature and power supply voltage; it indicates, alarms or controls accurately.

This controller is best suited for use in indicating, warning or controlling of industrial quantities such as electric furnace temperature, injection type plastic molder temperature, package boiler's combustion, etc. The external appearance of this controller is shown in *Fig. 1*. A general description of the controller follows:

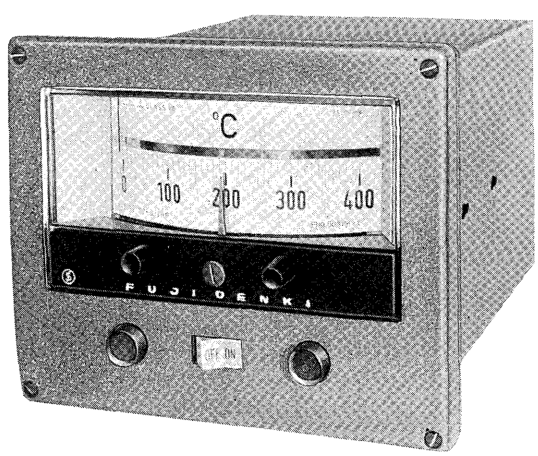

Fig. 1 Transistorized oscillator type controller (TZ-II)

II. OUTLINE OF OPERATION

1. Indicating Mechanism

1) Measuring element

The principal part of this controller; the pointer indicates measured values on a 110 mm calibrated scale. This measuring element is an external magnetic type which uses a unique span-band for the suspension of its moving coil. The span-band suspension method has been used in Fuji Electric's various meters; it has the following outstanding features:

(1) Absolutely no error due to friction
(2) High accuracy and durability
(3) Highly resistant against vibration and shock.

Because of the shielding effect of its case, the controller is not affected by external magnetic field or ferrous materials.

Table 1 shows the performance characteristics of this measuring element. As a thermometer, it completely fulfills the requirements prescribed by JIS for class 1.0 thermo-electric and resistance type meters; outside of its tolerance deviation, it is equal to JIS class 0.5 in all respects.

2) Current and voltage measurements

The current that flows through the controller is divided by a built-in shunt. The current that flows through the measuring element is limited to 100 μa (the current sensitivity of the galvanometer). In a voltage measurement, a series resistance limits the current flowing through the measuring element to 100 μa. When measuring temperature using a thermo-couple, this controller indicates the temperature accurately because of a built-in cold junction temperature compensator.

3) Resistance measurement

Current flowing through the measuring element, as in the cases of current and voltage measurements, is limited to 100 μa by means of voltage stabilizer and bridge circuit. *Fig. 2, 3* and *4* show voltage stabilizer connection, voltage and temperature characteristics respectively.

4) Adjusting circuit for wiring resistance (*Fig. 5*)

The following is an explanation of the function of this circuit as applied to temperature measuring

Table 1 Measuring element performance list

	Thermo-couple thermometer		Resistance thermometer	
	TZ-II	JIS 1.0 class	TZ-II	JIS 1.0 class
Permissible error	±1.0%	±1.0%	±1.0%	±1.0%
Friction	0	0.4 mm	0	0.4 mm
Effect of ambient temperature	0.5%/10°C	0.5%/10°C	0.3%/10°C	0.5%/10°C
Effect of external magnetic field	immeasurable	4%/400 amp./m	immeasurable	1%/400 amp./m
Effect of external ferrous material	immeasurable	0.1%	immeasurable	
Internal resistance (PR)	10 Ω/mv	5 Ω/mv		
Internal resistance $\left(\begin{smallmatrix}IC\\CA\end{smallmatrix}\right)$	10 Ω/mv	2.5 Ω/mv		
Internal resistance (mv)	10 Ω/mv	5 Ω/mv		
Effect of supply voltage			0.5%±1.5%	0.5%/±20%

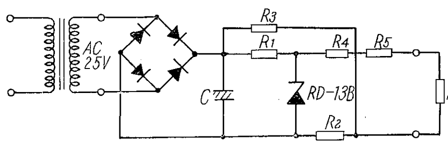

Fig. 2 Voltage stabilizer connection diagram

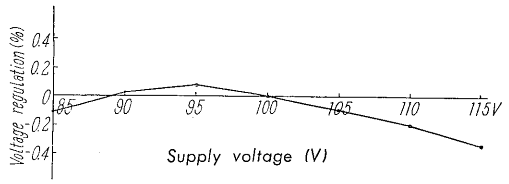

Fig. 3 Voltage stabilizer voltage characteristic

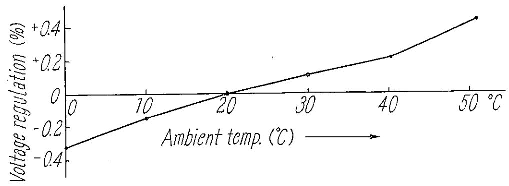

Fig. 4 Voltage stabilizer temperature characteristic

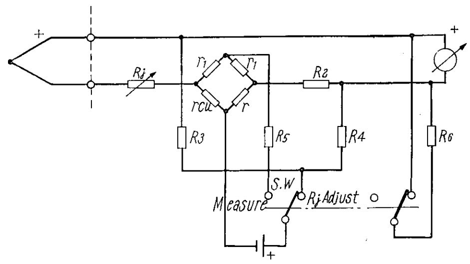

Fig. 5 External resistance adjusting circuit connection diagram

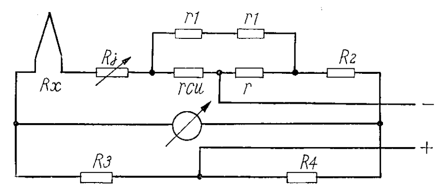

Fig. 6 Resistance adjusting equivalent circuit

using a thermo-couple. This circuit forms a bridge circuit using the measuring element as the galvanometer; by adjusting the circuit adjusting resistance (R_j), the pointer indicates zero. For instance, if the switch is turned to (R_j adjusting) before the temperature of the thermo-couple goes up, the pointer deflects according to the value of the external circuit resistance. Adjust the resistance R_j so that the pointer will indicate the mechanical zero.

Fig. 5 is redrawn, a bridge circuit with (R_x+R_j) as one of the sides, as shown in *Fig. 6,* is obtained. The balancing condition of this circuit can be expressed by the formula (1),

$$R_x+R_j=\frac{R_3}{R_4}\left(R_2+\frac{2r_1 r}{2r_1+r+r_{cu}}\right)-\frac{2r_1 r_{cu}}{2r_1+r+r_{cu}} \quad \cdots(1)$$

In this controller, the values of the resistance of the right side of the bridge are pre-determined so that R_x+R_j of the above formula will be 10 ohms.

Accordingly, if (R_j) is adjusted so that the pointer indicates the mechanical zero, the value of R_x+R_j will be 10 ohms, completing the adjustment.

2. Control Mechanism

The control mechanism will be described using a temperature control as an example.

In *Fig. 7,* when the temperature of the object being measured rises, the indication becomes higher than the set point.

At the same time, the screen plate attached to the

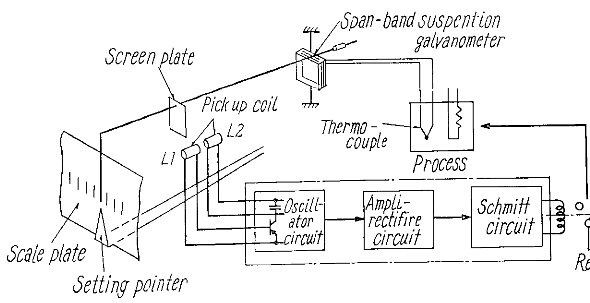

Fig. 7 Working principle diagram

pointer becomes a screen between the oscillator pickup coils, L_1 and L_2 mounted on the setting arm.

Because of the above, the mutual inductance between the coils L_1 and L_2 decreases. Therefore, the oscillator output voltage and output voltage of the amplifier-rectifier circuit (Schmitt circuit input voltage) also decreases. As a result, the relay is released by the Schmitt circuit. On the other hand, if the temperature of the object being measured decreases, the indication becomes lower than the set point; at the same time, the screen plate is removed from the space between the coils L_1 and L_2 and the mutual inductance between the coils L_1 and L_2 increases. The oscillator output and amplifier-rectifier circuit output voltages increase. As a result, the relay is operated by the Schmitt circuit.

Based on the above principle, the controller, as will be decribed later, is capable of very stable on-off response.

Fig. 8 shows the relationship between the input deviation and oscillator output voltage.

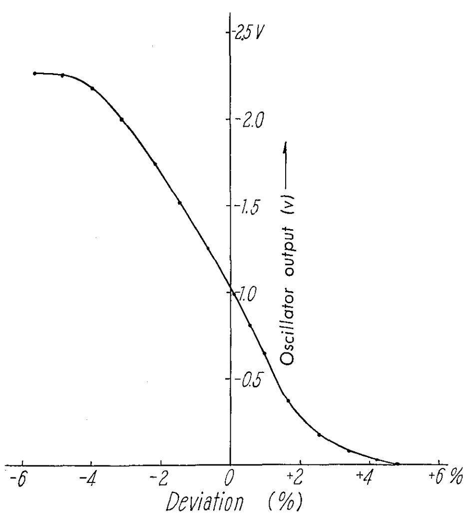

Fig. 8 Input deviation-oscillator voltage characteristic

1) On-off action

In "on-off" action, if the indication becomes greater than the set point, the relay releases; when the indication becomes less than the set point, the relay operates. The space between the operating and releasing points of the relay is called a hysteresis band. The width of this band should be as narrow as possible, but if it is too narrow, a relay malfunction may be caused by a small external vibration and the relay may vibrate mechanically. In this controller, as shown in *Fig. 9,* the above is solved by a lagging feedback of a CR circuit. As a result, this controller has a narrow hysteresis band and performs fully stabilized actions regardless of vibration.

This principle is described below. The feedback circuit of *Fig. 9* is redrawn, it becomes as is shown in *Fig. 10.* When the relay releases, the contact points b–c close to form a charging circuit. Conversely, when the relay operates, the contacts a–c close to form a discharge circuit.

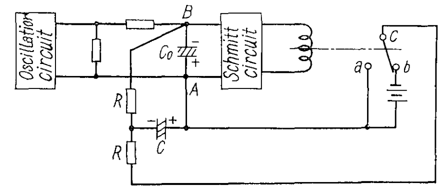

Fig. 9 Feedback circuit principle diagram

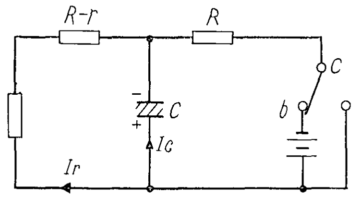

Fig. 10 Charging-discharging circuits

In *Fig. 10,* if the maximum value of the voltage at the ends of the resistance r is taken as V_{fm}, the voltage V_f across the resistance r t seconds after the relay releases can be expressed by formula (2).

$$V_f = V_{fm}\left(1 - e^{\frac{-t}{T}}\right) \quad \ldots\ldots\ldots\ldots (2)$$

On the other hand, the voltage V_f across the resistance r t seconds after the relay operates is expressed by formula (3).

$$V_f = V_{fm}\, e^{\frac{-t}{T}} \quad \ldots\ldots\ldots\ldots (3)$$

where $T = \frac{RC}{2}$ (time constant)

This voltage V_f is termed feedback voltage. The maximum value of the feedback voltage V_{fm} can be adjusted by varying the resistance r.

V_{fm} of the formulas (2) and (3) is equal to V_{on}-V_{off}-ΔV and the sum of the feedback voltage V_f and the oscillator output voltage is impressed between A–B of the Schmitt circuit input shown in *Fig. 9.*

The relay operates when the Schmitt circuit input voltage (the voltage of A–B of *Fig. 9* which will be called V_{AB} hereafter) is V_{on} and releases at V_{off} When the relay releases, feedback voltage as shown in the charging curve of *Fig. 11* is impressed on A–B. Conversely, when the relay operates, the voltage impressed on A–B by feedback decreases along the discharging curve of *Fig. 11.* An explanation will be made referring to *Fig. 11.*

Suppose that the pointer movement, compared to the time constant T of the feedback CR circuit is greatly retarded. As the deviation moves from negative to positive or as the input is increased and the indication nears the set point, V_{AB} decreases along a–b–c of the curve of *Fig. 11.* As the deviation reaches $+\Delta T$, V_{AB} becomes V_{off} and the relay releases. As a result, V_{AB} rises along the charging curve with time and becomes V_{on}-ΔV. In other words, it moves

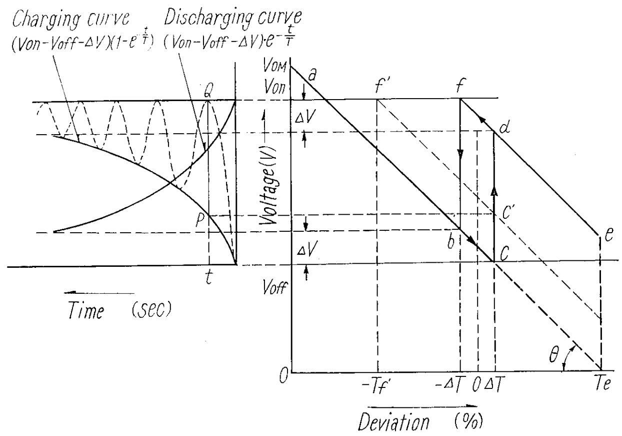

Fig. 11 Explanatory diagram of on-off action

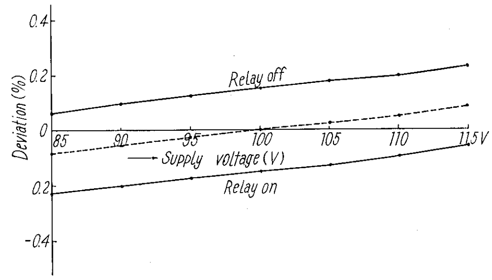

Fig. 12 On-off action voltage characteristic

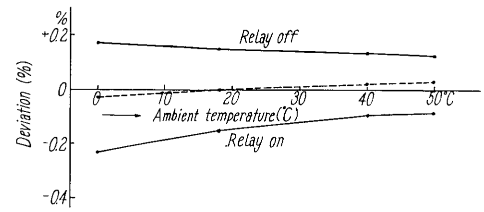

Fig. 13 On-off action temperature characteristic

from point c to point b of *Fig. 11*. Further, as the deviation becomes positive, V_{AB} (oscillator output voltage plus feedback voltage) decreases along the curve d–e.

On the other hand, as the deviation moves from $+\Delta T$ to $-\Delta T$, V_{AB} rises along the d–f curve of *Fig. 11* and reaches point f. As a result, V_{AB} changes to V_{on} and the relay operates, closing the contacts a–c; V_{AB} decreases along the discharging curve and becomes V_{off} $+\Delta V$, or it moves from point f to point b.

As it has been explained above, the relay operates when the deviation is $-\Delta T$ and releases at $+\Delta T$. Therefore, the hysteresis band is $2\Delta T$. The relationship between $2\Delta T$ and ΔV, if the slope of the deviation-oscillator output voltage curve is taken as tan θ, can be expressed with the formula (4).

$$2\Delta T = \Delta V/\tan\theta \quad \dots\dots\dots\dots\dots\dots (4)$$

Acccordingly, the hysteresis band $2\Delta T$ may be adjusted to suitable value by changing ΔV with amount of feedback.

With a feedback of this description, the controller is stable even against excessive vibration. This will be explained by referring to *Fig. 11*. To have the relay operate t seconds after its releasing, V_{AB} must rise from P to Q point in *Fig. 11*. If this is transduced into deviation, it must change from $+\Delta T$ to $-T_f'$. Stated conversely, if the variation of the deviation is from $+\Delta T$ to less than $-T_f'$, the relay does not operate. This is equivalent to an increase in the hysteresis band. The hysteresis band converted to a voltage value is the difference indicated by broken line between V_{on} and charging curve shown at the left in *Fig. 11*. That this decreases with time and that it becomes ΔV with sufficient lapse of time can be clearly understood from *Fig. 11*. *Fig. 12* and *13* show "on-off" action, voltage and temperature characteristics.

2) Proportional action

This can be explained by using temperature control as an example. To keep the temperature of a furnace at a set value, it is necessary to obtain the required heater output. Also, when the set value and load change, the corresponding output must be obtained. This controller controls the temperature automatically with a single heating unit. The reason for this is that this controller, by changing the proportion of the time T_{on} during which the power is supplied to the heater and the time T_{off} during which the power is off to obtain an average value, causes the heater to produce a suitable output. In this controller, the proportion of the time T_{on} during which the relay is operating and the time T_{off} during which the relay is not operating is changed by the oscillator output voltage or the temperature deviation. Thus an output proportional to the deviation can be obtained.

$$\rho = \frac{T_{on}}{T_{on} + T_{off}} \quad \dots\dots\dots\dots\dots (5)$$

When the deviation is more negative than $-\Delta T_p$, the relay continues to operate. Therefore, ρ is equal to 1. On the contrary, if the deviation is more positive than $+\Delta T_p$, the relay stays open. Thus $\rho=0$. When the deviation is between $-\Delta T_p$ and $+\Delta T_p$ the relay repeats on–off responses, and the proportion between the time T_{on} and T_{off} changes. As a result, ρ changes from $\rho=1$ to $\rho=0$. $2\Delta T_p$ at this time is called a proportional band.

A specific case of controlling a furnace of capacity W with this controller will be studied. From the formula (5), the average output of the furnace becomes ρ_W.

This average output ρ_W is a function of the deviation and varies from W to zero within the proportional band.

If the cycle T ($T = T_{on} + T_{off}$) of the relay is sufficiently small compared to the time constant of the furnace, the furnace temperature balances at a certain temperature t within the proportional band. That is, there is practically no variation in the control result. The set temperature t_0 and the control result or the balanced temperature t have the following relationship: the average output when the deviation is t_0-t and the furnace capacity required to bring the furnace temperature to t are equal. This deviation t_0-t is called an offset; without the addition of an integral action, it does not become $t_0=t$ automatically. The integral action is not used in this controller but t_0 can be made to equal t by means of a manual offset correcting device. This controllers's proportional action characteristic is shown in *Fig. 14* and proportional action temperature characteristic and voltage characteristic are shown in *Fig. 15* and *Fig. 16* respectively. The principle of the proportional action will be explained using *Fig. 17*.

As in the case of "on-off" action, the principle diagram is shown in *Fig. 9*. Compared to the maximum feedback voltage V_{fm} of "on-off" action, the maximum feedback voltage V_{pm} of the proportional action is made large. The voltages V_{fm} and V_{pm} must satisfy the conditions of the formulas (6) and (7).

$$V_{fm} < V_{on} - V_{off} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

$$V_{on} - V_{off} < V_{pm} < V_{on} \quad \ldots\ldots\ldots\ldots \quad (7)$$

In *Fig. 17* (a), the feedback voltage is added to the oscillator output voltage and the sum V_{AB} becomes V_{on}. For instance, *Fig. 17* (a), when the point A is reached, the relay operates. As a result, the contacts a–c of *Fig. 9* close and discharging starts; the feedback voltage decreases gradually, and the voltage V_{AB} becomes V_{off}. When the point B in *Fig. 17* (*a*) is reached, the relay releases and the contacts b–c of *Fig. 9* close and charging begins. The feedback voltage, therefore, rises along the charging curve. V_{AB} moves from the point C to the point A of *Fig. 17* (a) and the relay operates.

The above actions are repeated and the relay repeats on and off. As the oscillator output voltage decreases gradually from V_1 to V_2, V_3, etc., or as the deviation moves from negative toward positive, the time T_{on} becomes less than the time T_{off}. This condition may be understood from a study of *Fig. 17*. In *Fig. 17* (b), the setting and indicating values are coincident with each other, and T_{on} T_{off} are equal.

Let V_{on} = voltage between A–B of *Fig. 9* at which the relay operates,

V_{off} = voltage between A–B at which the relay releases

V_{pm} = maximum feedback voltage

V_0 = oscillator voltage,

then, T_{on} and T_{off} can be expressed by the formulas

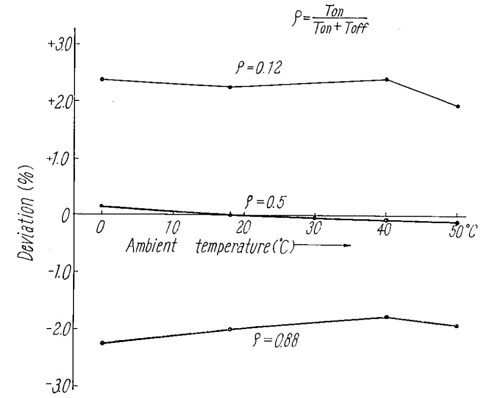

Fig. 15 **Proportional action temperature characteristic**

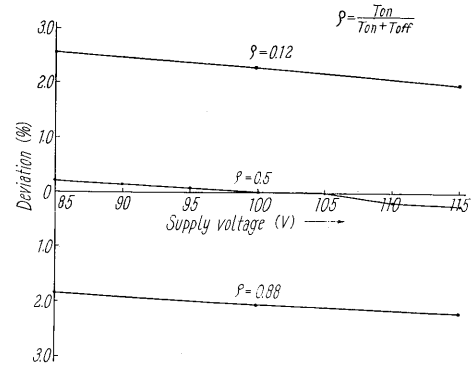

Fig. 16 **Proportional action voltage characteristic**

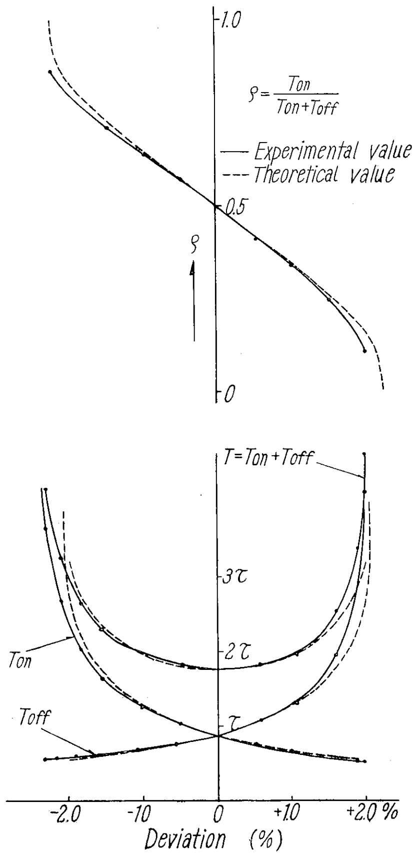

Fig. 14 **Proportional action characteristic**

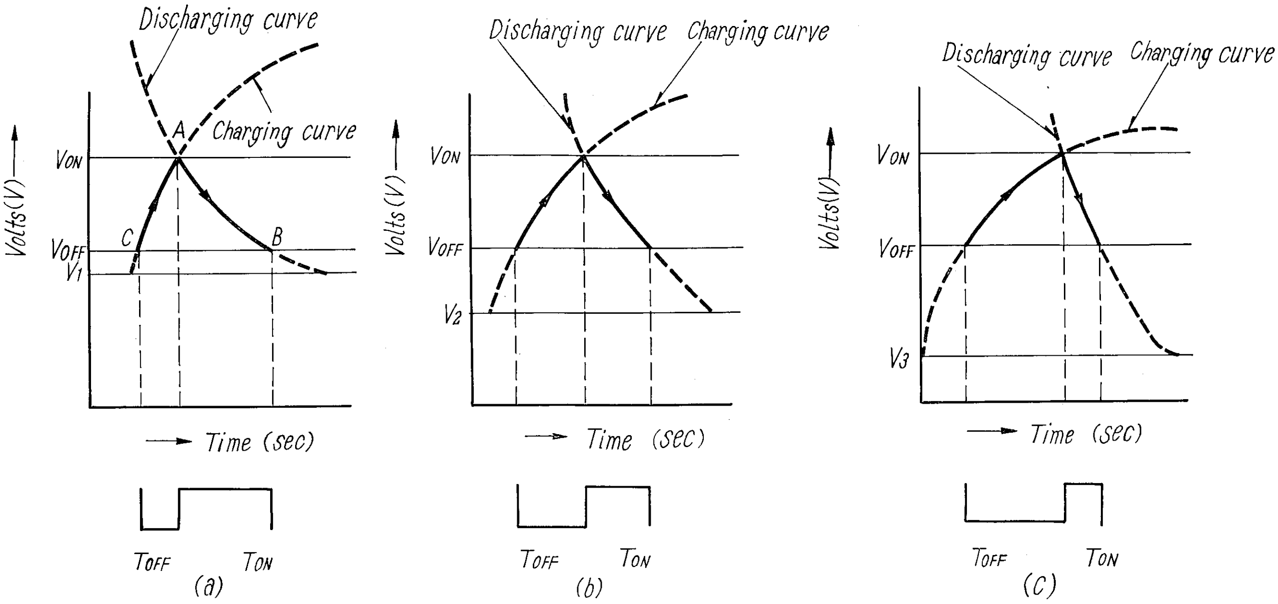

Fig. 17 **Illustration of proportional action**

of (8) and (9) respectively.

$$T_{on} = T \cdot l_n \frac{V_{on} - V_0}{V_{off} - V_0} \cdots\cdots\cdots\cdots\cdots\cdots \quad (8)$$

$$T_{off} = T \cdot l_n \frac{V_{pm} + V_0 - V_{off}}{V_{pm} + V_0 - V_{on}} \cdots\cdots\cdots\cdots \quad (9)$$

where $T = \frac{CR}{2}$ (time constant)

3) Derivative action

This controller performs a derivative action as well as a proportional action. It functions to maintain the indication at the setting value during rapid load variations for stable control. The derivative action of this controller is described below.

When the in-put changes rapidly toward positive direction, the time for the relay's initial operation is made short or the time for the initial releasing of the relay is made longer to cause the in-put to swing in the negative direction. On the other hand, if the in-put changed rapidly in the negative direction, the controller lengthens the time of the initial relay operation or shortens the time of the initial relay releasing, bringing the in-put in the positive direction.

Fig. 18 shows a condition in which the oscillator voltage is increased by ΔV because of a rapid change of the deviation in negative direction directly after the relay had operated at the oscillator voltage V_0. The time for the relay's initial operation is longer by ΔT_{on} than the relay's operating time T'_{on} when the oscillator voltage is $V_0 + \Delta V$.

In *Fig. 18,* when the oscillator voltage is V_0, the relay operates at the point *A* and releases at the point *B*. Next, if the oscillator voltage is increased by ΔV immediately after the relay operates at point

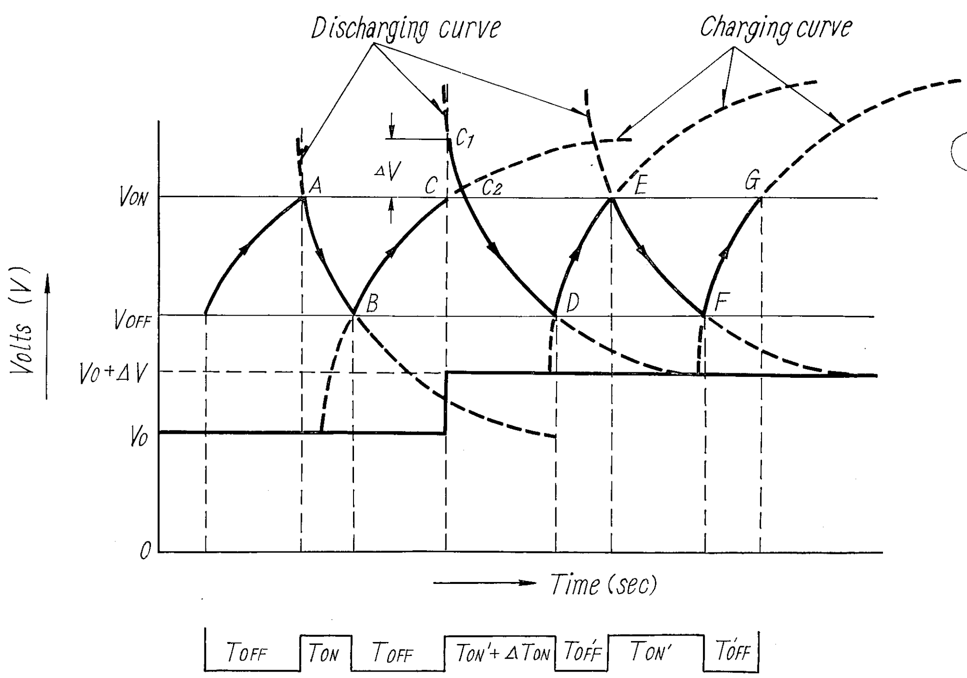

Fig. 18 **Illustration of derivative action**

C, the point C moves to the point C_1. Therrefore, the relay's initial operating time is the time during which V_{AB} takes in decreasing from the point C_1 to point D along the discharging curve. After the relay releases at the point D, the controller performs normal operation of $V_0+\Delta V$. The relay's releasing time T_{off} is the time during which V_{AB} rises from the point D to the point E or from the point F to the point G along the charging curve. The relay's operating time T_{on}', moreover, is the time during which V_{AB} decreases from the point E to point F or from the point C_2 to the point D along the discharging curve. Therefore, the time for the relay's first operation when the oscillator voltage is larger by ΔV because of a rapid change of the deviation in the negative direction immediately after the relay has operated at the point C, is longer, compared to T_{on}', by the time ΔT_{on} during which V_{AB} decreases from the point C_1 to point C_2 along the discharging curve.

When the deviation changes rapidly in the positive direction and the oscillator voltage is decreased, the controller operates just opposite to the above, to shorten the relay's initial operating time or lengthen the initial releasing time to bring the deviation in the negative direction.

Variation ΔT_{on} of the relay's first operating time when the oscillator voltage has changed from V_0 to $V_0+\Delta V$ at a rapid change of deviation immediately after an operation of the relay is expressed by the formula (10) and the variation ΔT_{off} of relay's first releasing when the oscillator voltage has changed from V_0 to $V_0+\Delta V$ immediately after a releasing of the relay is expressed by the formula (11).

$$\Delta T_{on}=T\cdot l_n\frac{V_{on}-V_0}{V_{on}-V_0-\Delta V}\cdots\cdots\cdots\cdots (10)$$

$$\Delta T_{off}=T\cdot l_n\left(1+\frac{\Delta V}{V_0+V_{pm}-V_{off}}\right)\cdots\cdots (11)$$

where, T=time constant

Here, when the deviation changes rapidly in the negative direction, $\Delta V>0$; when the deviation changes rapidly in the positive direction, $\Delta V<0$.

III. RELAY

The relay used in this controller is FUJITSU's relay No. 34. This relay is provided with large silver contacts; it has a large capacity contact of 1 kw (maximum voltage 200 v and maximum current 8 amp.). Moreover, since the relay is equipped with a spark quencher using a varister, it can be used directly to drive heaters, electromagnetic switch, electromagnetic valves and saturable reactors, etc. Its cover is made of polycarbonate and is moisture-proof. Because of its plug-in construction, handling is simple. Its contacts will last for more than several million operations in practice.

IV. CONCLUSION

We have described the principle, construction and features of the transistorized oscillator type controller, TZ–II. This controller operates with stability regardless of external conditions, power supply voltage variation and environmental temperature changes. Moreover, it performs indicating, warning or proportional actions. Derivative action can be added to the proportional action for more stabilized controlling.

Handling is extremely simple; for adjusting external circuit resistance, all that is needed is only to adjust R_j so that the pointer indicates the mechanical zero point.

Because of its excellent performance and many advantages, we believe that this controller will be used extensively. We will consider fully the users' requirements, recommendations, etc., and strive to add more improvements to this instrument.